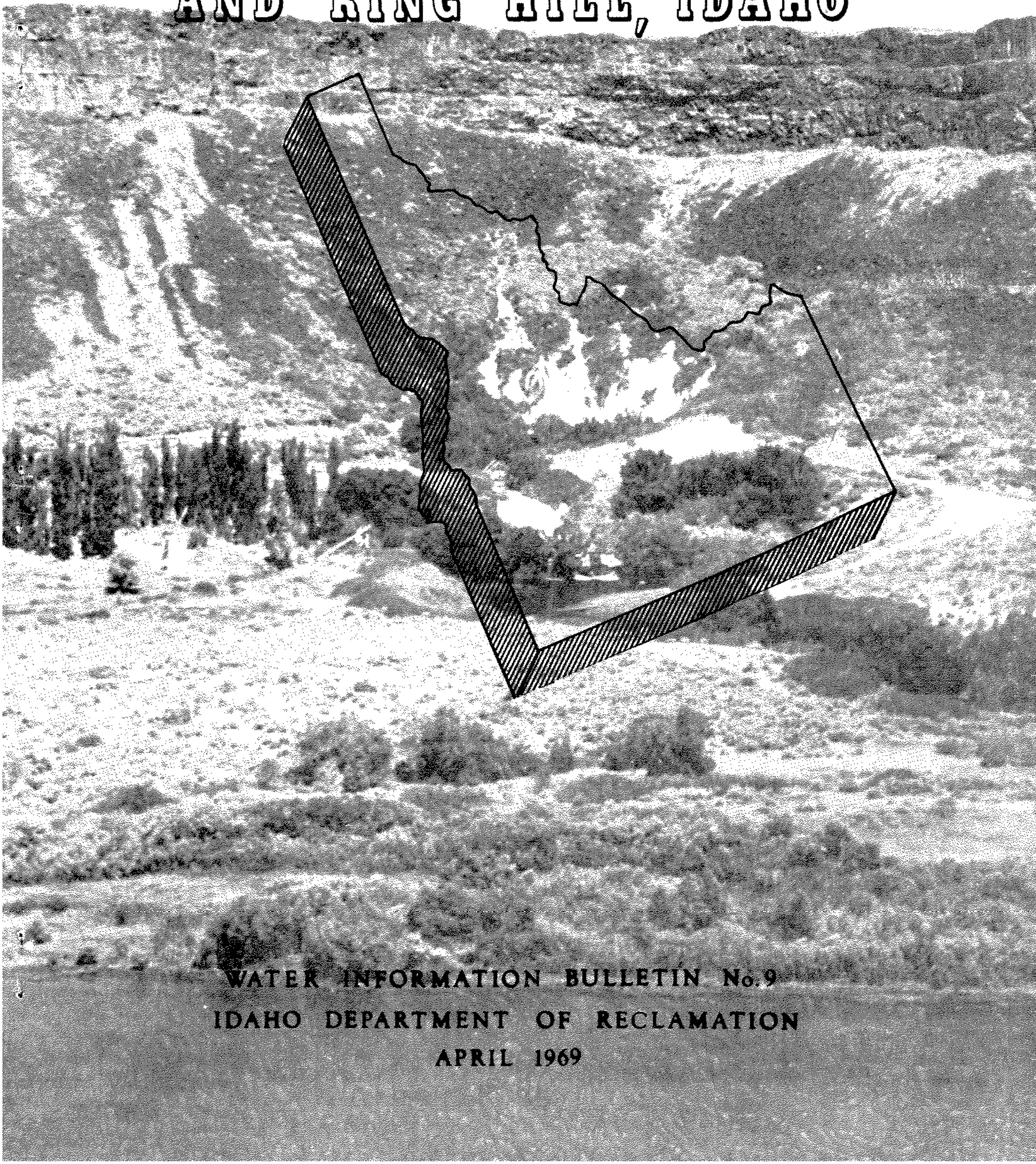
# INFLOW TO THE SNAKE RIVER BETWEEN MILNER AND KING HILL, IDAHO



WATER INFORMATION BULLETIN No. 9

IDAHO DEPARTMENT OF RECLAMATION

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# INFLOW TO SNAKE RIVER BETWEEN MILNER AND KING HILL, IDAHO

By

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## ABSTRACT

Because of its size and location, the water supply entering the Snake River between Milner and King Hill is a resource of considerable economic value. The principal source of this supply is the springs along the north bank of the river. The springs discharge water from the Snake Plain aquifer, which underlies most of the Snake River Plain. The hydrologic and geographic features of the supply are shown on maps and graphs and are described briefly. Stream and spring discharge records permit reasonably accurate estimates of inflow to the Snake River from both north and south side sources. The estimates are basic to studies assessing the impact of man's activities on the supply and to predict the inflow for management purposes. Generally, inflow to the study reach fluctuates in a comparatively narrow range compared with other large uncontrolled surface-water supplies.

Total inflow during the water years 1910-66 averaged 7,400 cfs (cubic feet per second) or 5.4 million acre-feet per year. An estimated 5,900 cfs issued from the scores of springs along the north bank of the river while about 1,500 cfs was contributed from all south-side sources and by surface flow from the north side. Inflow to the reach increased from 5,500 cfs in 1910 to 8,300 cfs in 1953 as a result of increased irrigation diversions. However, starting in 1953, pumping from the Snake Plain aquifer began to affect the inflow noticeably. Pumping and a decrease in recharge reduced the inflow to about 7,000 cfs in 1962. Subsequently, an increase in recharge

raised the inflow to about 7,800 cfs in 1965.

The annual mean inflow to the reach and the total spring flow correlate significantly with a recharge index which is the sum of flows diverted onto the plain for irrigation plus tributary flows onto the plain. Pumping from the aquifer is the principal cause of departures from this correlation since 1953. The departures correlate well with the net pumpage (that part of the pumped water which is used consumptively) from the aquifer. Using the correlations and snow survey data, excellent forecasts of the spring flows and of the total inflow to the reach can be made. Probable effects on the inflow caused by changes in diversions for irrigation, artificial recharge of the aquifer, pumping from the aquifer, and variations in water use can be approximated from these relations.

The quality of the water entering the reach is excellent for irrigation, but treatment would be required for municipal and some industrial uses. Chemical analyses of the spring waters showed that dissolved solids range from 382 mg/l (milligrams per liter) in Blue Lakes Spring to 217 mg/l in Riley Creek, gradually decreasing from the upstream to the downstream springs. Dissolved solids in the flows in the south-side channels averaged 560 mg/l. The composite dissolved solids of the total inflow was found to be 328 mg/l.

## INTRODUCTION

The water supply entering the Snake River between the gages at Milner, 0880 (numbers are site identification numbers and conform with those in figures 2-10), and at King Hill, 1545 (fig. 2), herein termed the study reach, is unique. Inflow at the upper end of the reach is almost entirely controlled by reservoirs and irrigation diversions. The flow passing Milner Dam is very small during many years and is less than 100 cfs for extended periods during most irrigation seasons. However, the flow at King Hill, 94 miles downstream, seldom is less than 7,000 cfs, the increase being derived largely from springs and seepage entering below Milner.

The magnitude, location, and uniformity of the supply combine to make this inflow a resource of considerable economic value for hydroelectric power, irrigation, fish propagation, recreation, and other uses. Large acreages in new irrigation projects above and below King Hill receive water by pumping directly from the river, and applications for additional diversions that total considerably more than the average flow of the Snake River at King Hill during the irrigation season are on file with the Idaho State Reclamation Engineer. The expanding economies of Idaho and adjoining states continue to intensify competition for the use of the Snake River water. Flow in the Snake River presently furnishes all or part of the energy for more than a score of hydroelectric power plants between Milner and the Pacific Ocean.

Inflow to the Snake River between main-stem gaging stations at Milner, 0880, and at King Hill, 1545, averaged 7,400 cfs (5.4 million acre-feet per year) during the water years 1910-66. This does not include the flow at gaging station Big Wood River near Gooding, 1545, which has been deducted from the inflow in the reach for the purposes of this study, nor does it include the flow which bypasses the Snake River gage at King Hill through the King Hill Canal. Of the inflow in the reach, an estimated average of 5,900 cfs (4.3 million acre-feet per year) issued from the scores of springs along the north bank of the river, while about 1,500 cfs was contributed by all south-side sources and by surface flow from the north side. The group of springs along the north bank includes 11 of the 65 springs in the United States that are classified as first magnitude and have an average discharge in excess of 100 cfs (Meinzer, 1927, p. 44).

## Purpose and Scope

Diversions for irrigation, reservoir storage, and other developments along the Snake River, over an extended period, have progressively changed the inflow to the study reach. Future developments will cause further changes. Knowledge of the characteristics of the inflow and the effects of works of man are vital for planning, proper management, and optimum utilization of the resource. Many standard statistical analyses of the records of inflow are inappropriate because of the bias resulting from these changes. For example, magnitude and frequency of flows, flow duration, means, etc., for the period of record would be misleading. Inflow data for the reach could be used properly for such statistical analyses only after involved adjustments which are beyond the scope of this report.

This report identifies and quantifies changes that have occurred in the inflow to the study reach and to several subreaches during periods of rapidly increasing water-use development. Comparative changes in the subreaches are illustrated by the use of hydrographs. Simple correlations are illustrated which provide a basis for predicting inflow. The correlations also indicate some of the effects on discharge from the Snake Plain aquifer that result from pumping.

The available records of flow in the individual springs through water year 1967 and detailed descriptions of the springs are included in other reports (Nace and others, 1958; Thomas, 1968).


## Acknowledgements

This report was prepared by the U. S. Geological Survey in cooperation with the Idaho Department of Reclamation. Discharge data on which determinations made in this report are based were taken from surface-water records published by the U. S. Geological Survey. The lengthy list of annual reports and compilations from which these records were obtained is given in other reports (Nace and others, 1958, p. 8-9; Thomas, 1968, p. 14-15; U. S. Geological Survey, 1956, p. 10-11, and 1963, p. 5).


## Site-Numbering System

All spring and stream measuring sites are identified with a number, 1545, for example. The numbers increase in a downstream direction in conformance with the system used in the annual surface-water reports of the U. S. Geological Survey. Numbers bearing a prefix "M" denote a site where miscellaneous measurements were made; those without the prefix are stations where a continuous record was obtained. For convenience the part number (13), which designates a site as being in the Snake River basin, has been omitted from all references to station numbers listed in this report.

# DESCRIPTION OF THE HYDROLOGIC SYSTEM

Some major geographic features in the area covered by this report and the location of the study reach are illustrated on the index map (fig. 1) and on the map of the study reach (fig. 2). The detailed maps (figs. 3-6) show local features within the area. Because detailed descriptions of the

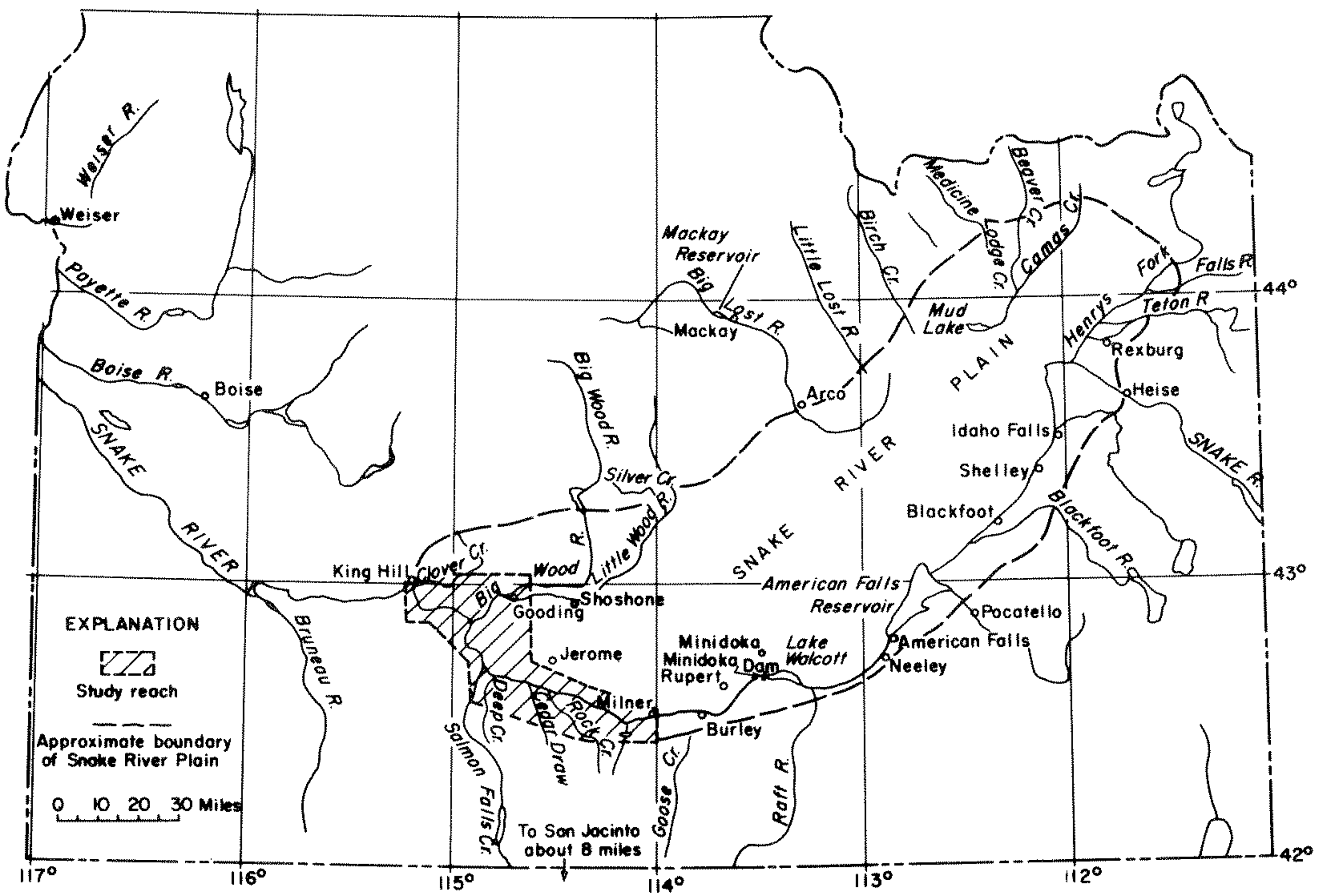


FIGURE 1.--Index map of southern Idaho showing the study reach and the Snake River Plain.

study reach and the associated hydrologic system are included in other reports (Mundorff and others, 1964; Stearns and others, 1938), only a summary description is given here.

All springs entering from the north side of the Snake River canyon (hereafter referred to as "the springs") discharge water from the large Snake Plain aquifer, which underlies most of the Snake River Plain. This aquifer is recharged by seepage from the Snake River and its tributaries along the eastern side of the plain, by surface streams flowing onto the plain from the mountains to the north, by infiltration from irrigation on the plain, and by precipitation directly on the plain. Quantities of recharge to the aquifer from the major sources were evaluated by Mundorff and others (1964). Seepage from the channel of the Snake River and from its tributaries accounts for a large share of the recharge. However, the contribution from irrigation on the plain is also large, and increased irrigation has caused significant increases in aquifer discharge. Precipitation over most of the plain averages less than 10 inches yearly. Recharge from this source is estimated to average about 1.1 inches, or only about 700 cfs of the total recharge rate (Mundorff and others, 1964).

Immediately above Milner Dam the river bed is slightly below the level of the Snake River Plain. However, in the 22-mile reach below the dam, the Snake River has cut a canyon which, below the Twin Falls of the Snake River, is as much as 400 feet deep. At Shoshone Falls the river drops more than 200 feet. Throughout the remaining 69 miles to King Hill, the river remains 400 to 600 feet below the level of the Snake River Plain (figs. 3-6).

The Snake River intercepts the Snake Plain aquifer near Devils Washbowl Spring, 0895, just above the Twin Falls of the Snake River (fig. 3), and remains below the water table throughout the remainder of the study reach. The river has direct contact with basalts of the Snake River Group along both its banks for about 45 miles below Milner. Approximately north of Buhl, the Snake River Group ends along the southerly bank, and just upstream from King Hill the river loses contact with the basalts. All of the springs discharge from the basalts. The last discharge from the aquifer, Bancroft Spring, M1537.8, enters about 7 miles above King Hill. The basalts along the river terminate in fluvial and lacustrine deposits that effectively block the ground-water flow parallel to the river channel, thus forcing all the ground water discharged by the Snake Plain aquifer into the Snake River above King Hill. Altitudes of spring openings, accessibility of springs, depth of canyon walls, location with respect to other topographic features, and other physical details are shown on the expanded map sections (figs. 3-6).

Beginning in about 1946, ground water has been pumped to irrigate new farmland on the Snake River Plain. Even though the quantity of surface water diverted has not changed materially since about 1920, pumping of ground water for irrigation in valleys along the margin of the plain has increased rapidly in recent years. Thus, pumping has become one of the principal discharges from the aquifer. Although major natural discharge from the aquifer occurs from springs in the vicinity of American Falls Reservoir, only the springs in the reach Milner to King Hill are considered in this report.

Canals on both banks of the reservoir formed by Milner Dam divert water for irrigation of more than 440,000 acres of land (fig. 2). The canals at Milner are the farthest downstream of those which divert by gravity from Snake River onto the plain. King Hill Canal diverts from Malad Springs near Hagerman (fig. 6), and it irrigates lands along the Snake River bottom, below the

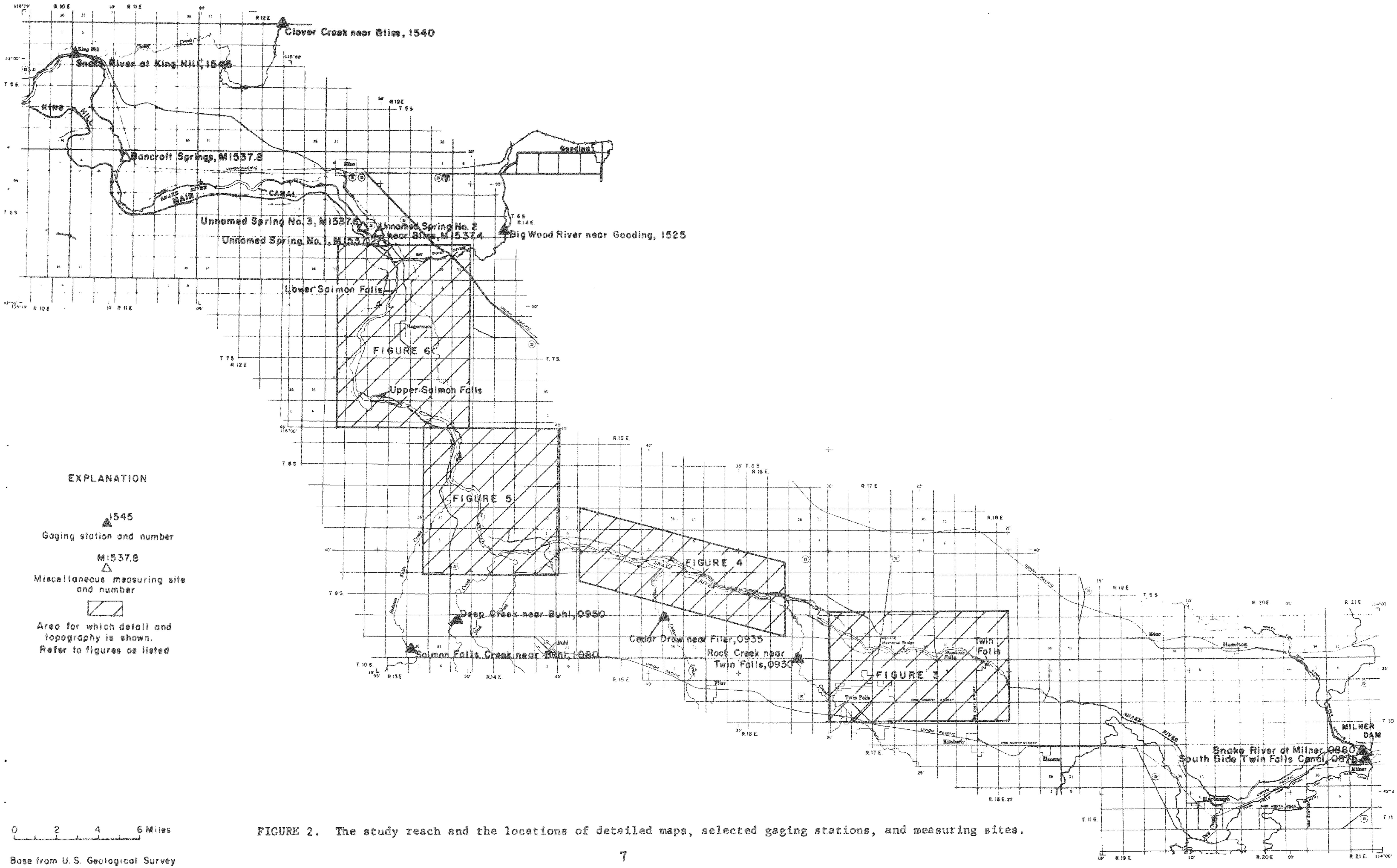


FIGURE 2. The study reach and the locations of detailed maps, selected gaging stations, and measuring sites.

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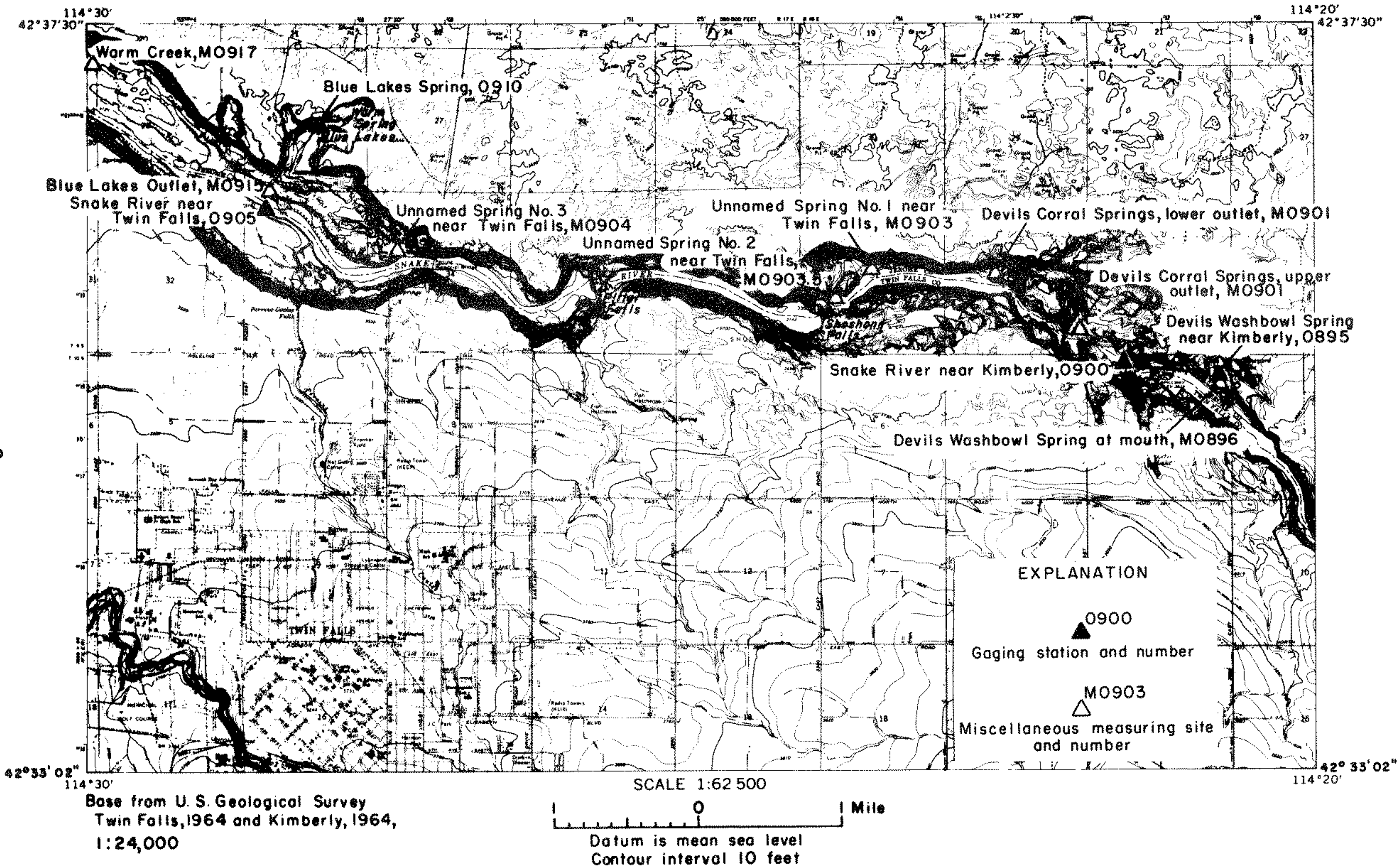


FIGURE 3. Topography and measuring sites, Devils Washbowl Spring, 0895, to Warm Creek, M0917.

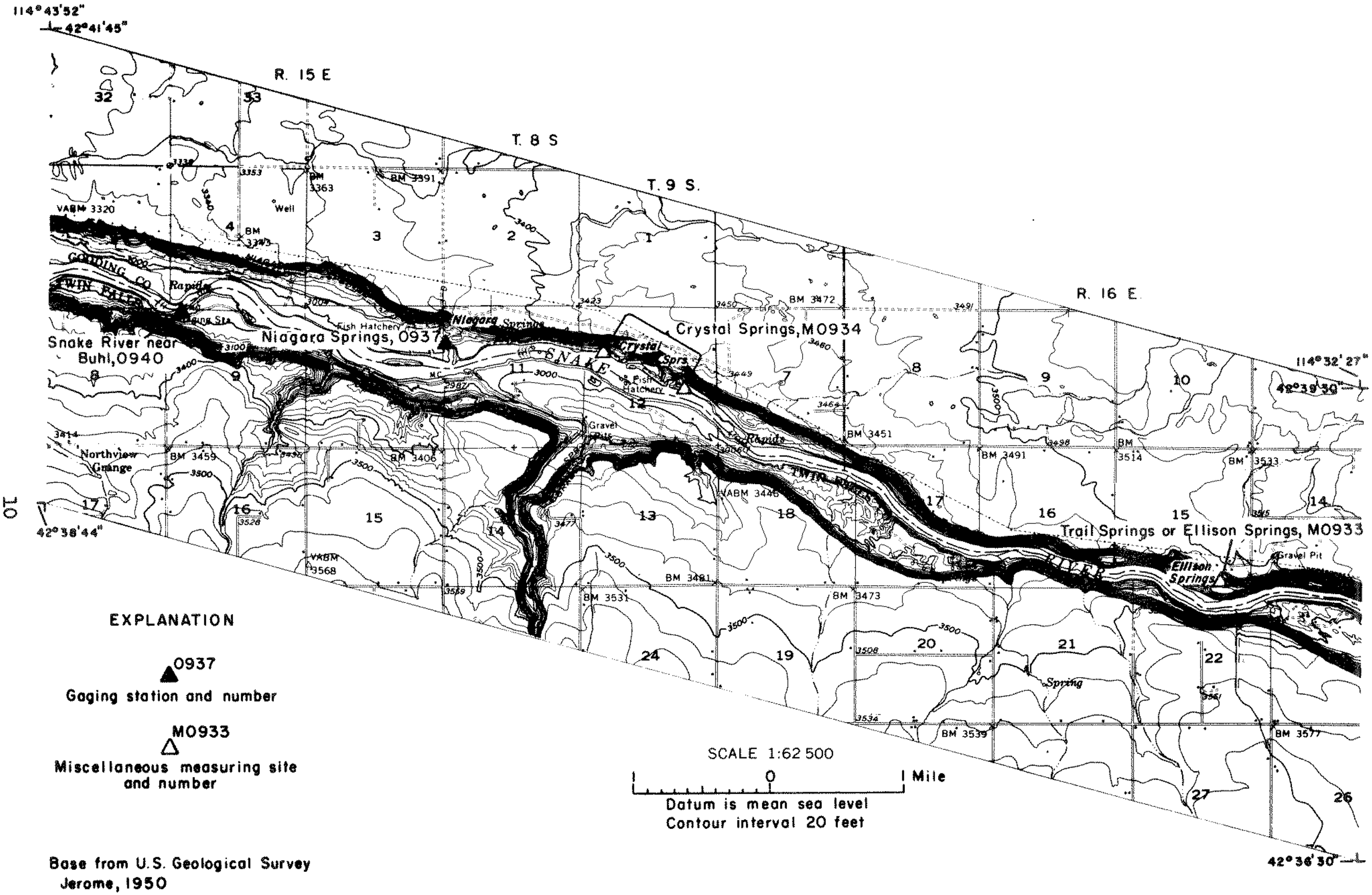


FIGURE 4. Topography and measuring sites, Ellison Springs, M0933, to Snake River near Buhl, 0940.

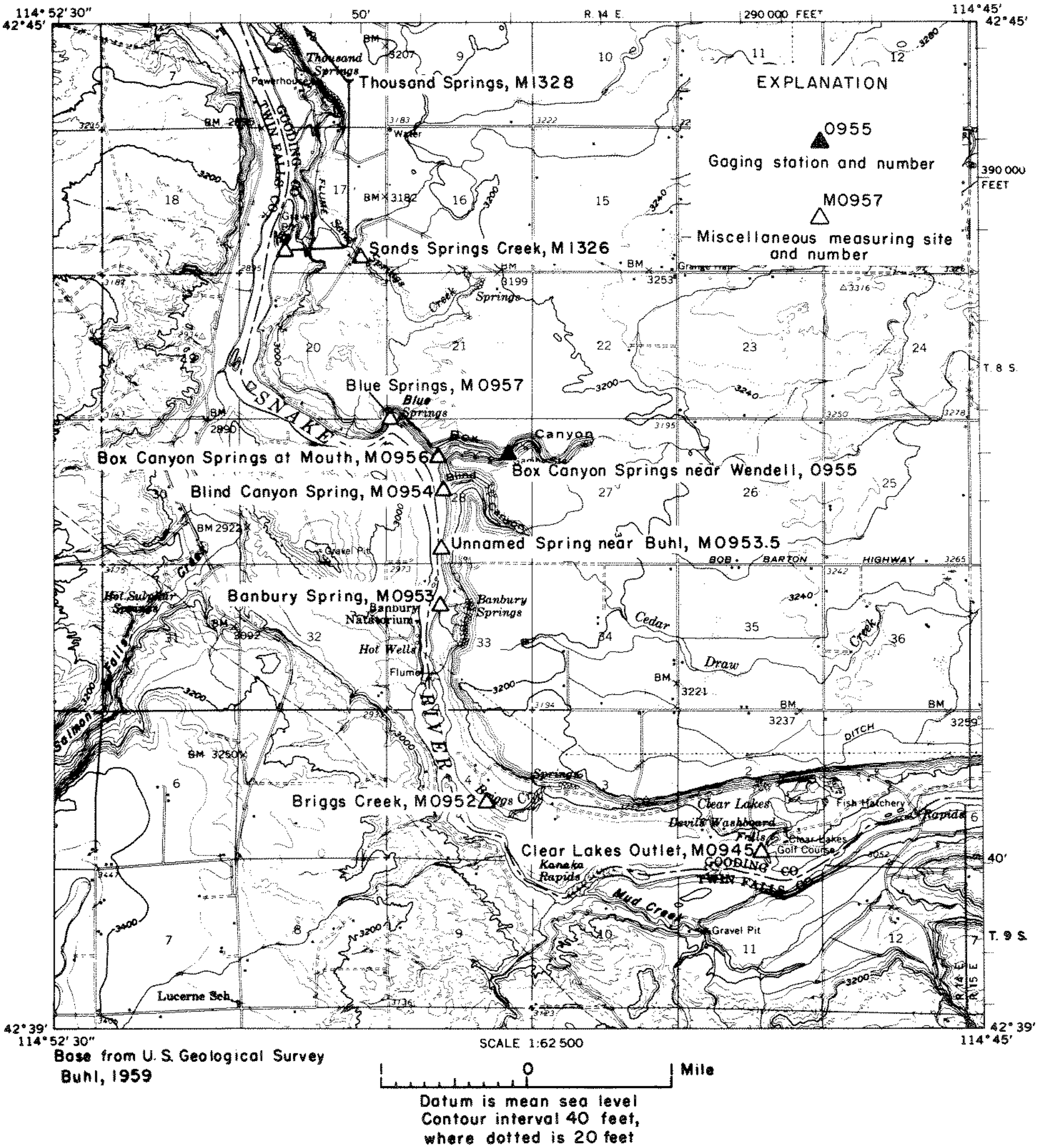


FIGURE 5. Topography and measuring sites, Clear Lakes Outlet, M0945, to Thousand Springs, M1328.

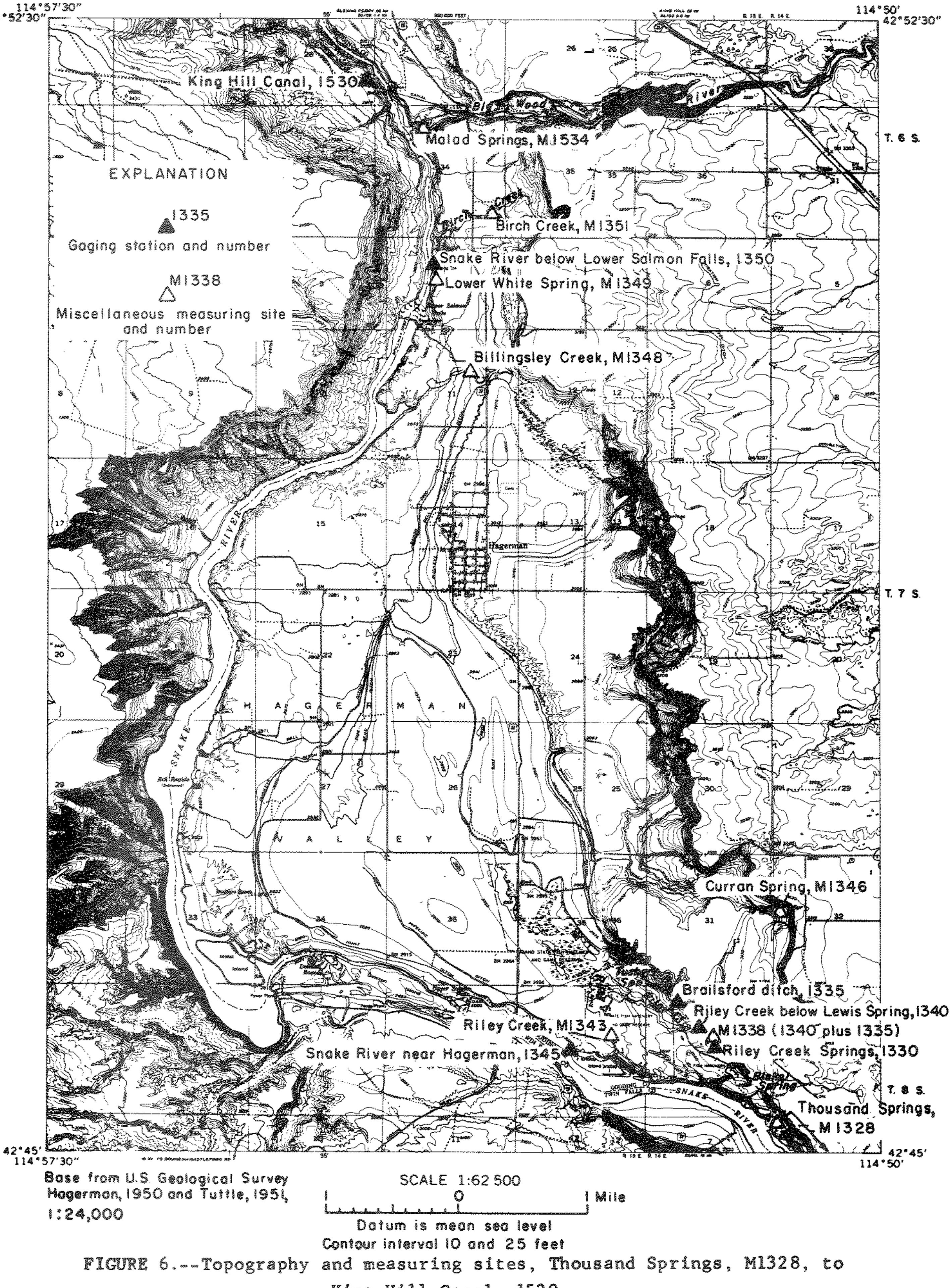


FIGURE 6.--Topography and measuring sites, Thousand Springs, M1328, to King Hill Canal, 1530.

level of the Snake Plain aquifer. At Minidoka Dam, 35 miles above Milner (fig. 1), canals divert water for irrigation of 118,000 acres. In all, about 1,340,000 acres of land are irrigated by diversions from Snake River or its tributaries above the gaging station at Milner. Reservoirs on the Snake River and its tributaries above Milner now impound about 4.7 million acre-feet of water. About 0.4 million acre-feet more, including Mackay Reservoir (fig. 1), is stored on tributaries between Milner and King Hill. The diversions and storage upstream from Milner, which have increased progressively since irrigation began, drastically deplete the river flow at Milner to the extent that practically no flow passes Milner for long periods.

## CHARACTERISTICS OF THE INFLOW

Excluding Big Wood River, overland runoff into the study reach of the Snake River directly from snowmelt or precipitation is practically nil. About three-fourths of the inflow is from springs fed by the Snake Plain aquifer. Most of the remainder is return flow from irrigation along the south side. The average magnitude of the major components of the inflow to the study reach for the period 1951-60 and the order of entry are illustrated graphically on figure 7. The quantities of inflow not measured in springs or return-flow channels were distributed uniformly between main-stem gaging stations unless some reason for a different distribution was known.

During the period of record, the manifold changes in storage, diversion, and pumping have strongly influenced the recharge to and the discharge from the aquifer and the other inflows to the study reach. Nevertheless, compared with most large unregulated surface-water supplies, the total inflow to the reach varied in a comparatively narrow range (fig. 8). Annual mean inflow was about 5,500 cfs in 1910, which was the lowest during the period 1910-66.

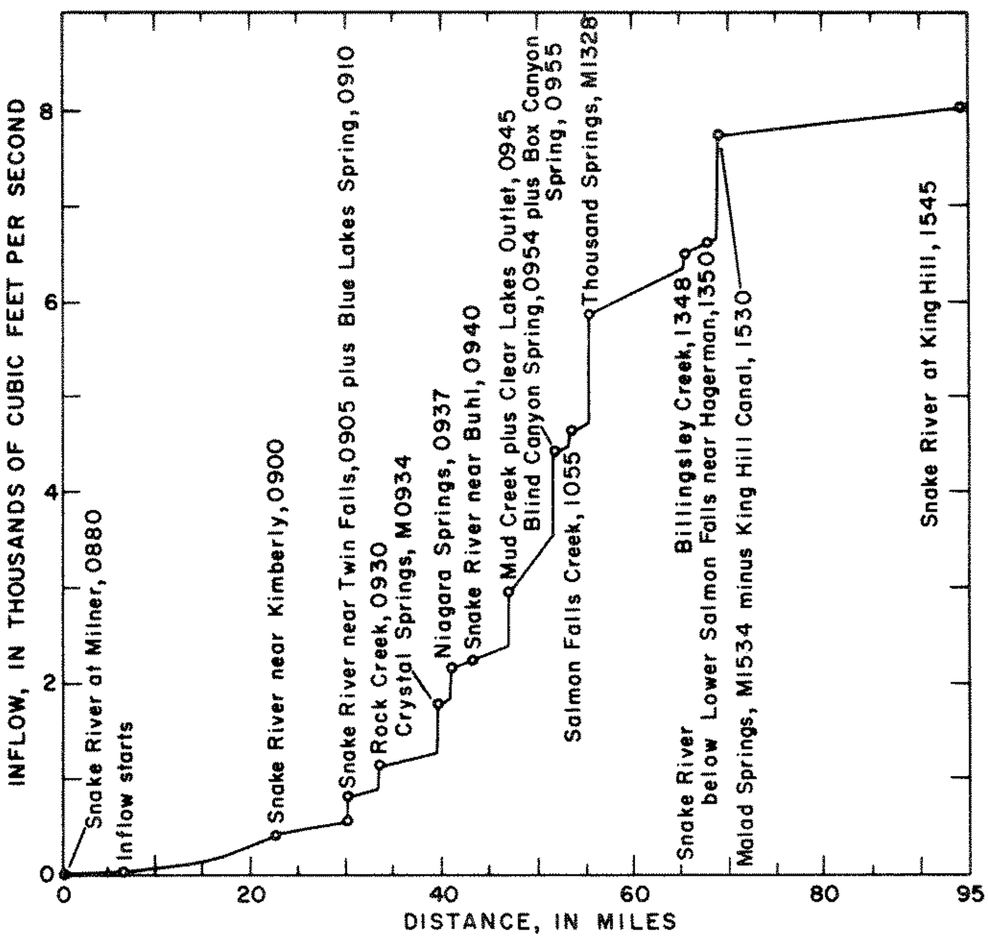


**FIGURE 7.** Increase of average inflow into the study reach, during the period 1951-60, with distance below Milner.

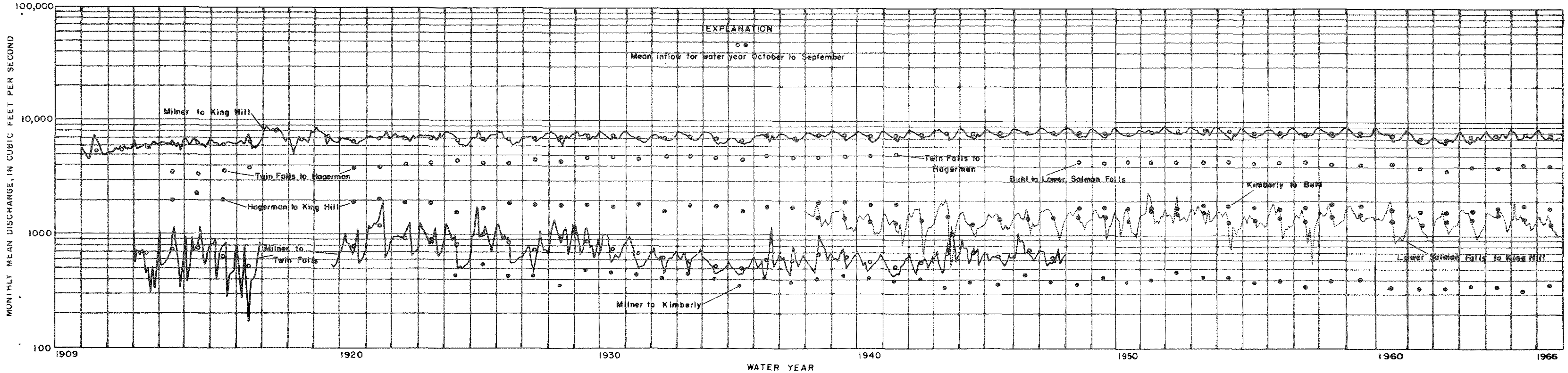


FIGURE 8.--The inflow to Snake River between main-stem gaging stations at Milner and King Hill.

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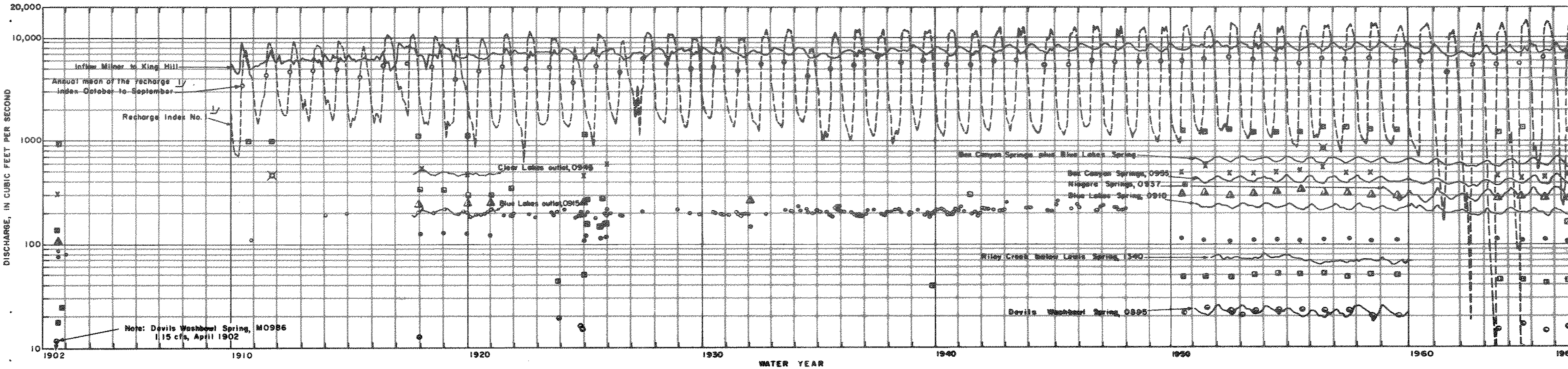
Inflow increased to an annual mean of about 8,300 cfs in 1953 when pumping from the Snake Plain aquifer began to affect the inflow noticeably. As a result of ground-water withdrawals and a decrease in recharge, the inflow decreased to about 7,000 cfs in 1962. Subsequently, an increase in recharge raised the inflow to about 7,800 cfs in 1965. An annual cyclical variation of the inflow is evident beginning in 1924 (fig. 8), with the lows typically in the spring months and the highs in autumn. The regularity of this pattern indicates that the changes are artificially imposed. The obvious causative factor is the seasonal application of irrigation water on the plain and the seasonal cyclical pattern of other flow which recharges the aquifer. An index designated Recharge Index No. 1, has been computed to illustrate the effect of recharge influences on the inflow and is plotted on figure 9 for the period 1910-66. The index is the sum of monthly mean diversions onto the plain from Snake River at Minidoka and at Milner plus the flow from Big Wood River and Goose, Salmon Falls, and Rock Creeks. This index is not adjusted for the time lag occurring between a particular recharge event and the corresponding change in inflow.

The inflow to the subreach between gaging stations Snake River at Milner, 0880, and Snake River near Kimberly, 0900, plotted on figures 8 and 10, enters the river mostly as seepage from south bank. Less than 20 percent of this segment of inflow appears as surface flow in measurable channels before reaching the river. In figure 10, the computed inflow for some months, see 1943 and 1957, are quite different from those for a month or two before and after. The Snake River was high during most of these months, and small inaccuracies in large river discharges can result in fictitious figures for the computed inflow. However, the river through much of this subreach is perched above the regional water table and the apparent low inflow may result from seepage away from the river when stages are above the low-water channel. The long-term trend of the flow in this subreach is downward (fig. 8), which contrasts with the trend in the flow in the springs.

The correlation of the inflow to the subreach Milner to Kimberly with the inflow to the subreach between gages Snake River at Milner, 0880, and Snake River near Twin Falls, 0905, as shown in the hydrographs of figure 8 permits a reasonable estimation of discharge for the Milner to Kimberly subreach for the periods 1912-16 and 1920-23 (fig. 8). The relation of the inflow Milner to Kimberly with the flow at the gaging station Rock Creek near Twin Falls, 0930, is reasonably good as shown on figure 10. The pattern of the total inflow from five sources (fig. 10) also corresponds reasonably with that for the inflow Milner to Kimberly. Since these are major parts of the total inflow from the south side for the entire study reach, and since they all correlate with each other, it may be inferred that the inflow Milner to Kimberly and the other large segments of the inflow that have been gaged are reasonably good indices of the total south-side inflow.

The inflow between river gages near Kimberly, 0900, and near Buhl, 0940, is more than 20 percent of the total inflow in the study reach (fig. 7). About two-thirds of the flow in this subreach is spring flow from the north side. The remainder is nearly all return flow from irrigation on the south side. Measurements show sizable variations in the south-side inflow to the subreach.

The subreach between the river gages near Buhl, 0940, and below Lower Salmon Falls, near Hagerman, 1350, receives more than half the total inflow to the study reach. About 10 percent of the inflow in this subreach is in




EXPLANATION

| | | | | | |
|---|---|---|---|---|---|
| M0896 Devils Washbowl Spring at mouth | 0915 Blue Lakes Outlet | 0937 Niagara Springs at gaging station site | 0955 Box Canyon Springs at gaging station site | M1343 Riley Creek at mouth | 1/ The Recharge Index No. 1 is the sum of the monthly mean diversions and stream inflows to Snake River Plain below American Falls, unadjusted for time lag (see text page 17). |
| M0901 Devils Corral Spring | M0934 Crystal Springs | M0952 Briggs Creek | M0956 Box Canyon Springs at mouth | M1534 Malad Springs | |

FIGURE 9.--Inflow from selected springs, Recharge Index No. 1, and the total inflow.

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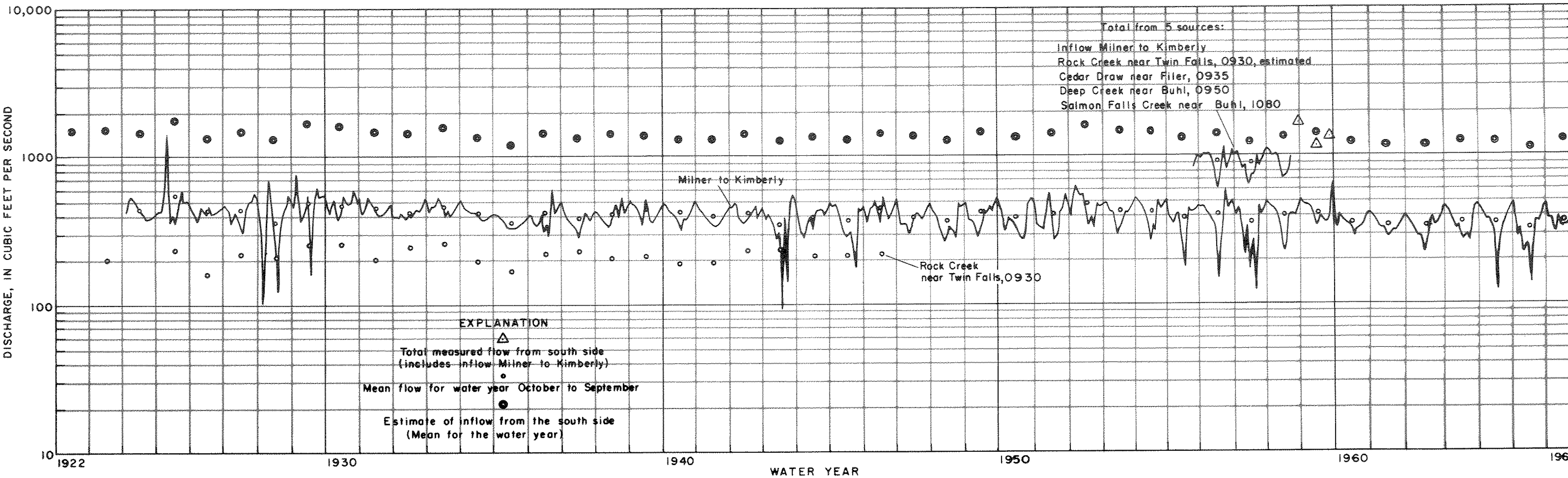


FIGURE 10. Inflow to Snake River from the south side.

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measurable wasteways from the south side, about two-thirds is from measured springs along the north side in the subreach, and the remainder flows from springs and seeps not measured, most of which are along the north side.

More than 80 percent of the inflow in the subreach between the river gages below Lower Salmon Falls, near Hagerman, 1350, and at King Hill, 1545, is from Malad Springs, M1534. Flow at the gage Big Wood River near Gooding, 1525, is deducted from inflow in this subreach as noted in the introduction.

The hydrographs indicate that, while there is a definite upward trend in the total inflow in the study reach until about 1953, an upward trend did not occur in the extreme upper or lower subreaches. Most of the sizable increase in the total inflow during the period of record developed in the subreach between the river gages near Kimberly, 0900, and below Lower Salmon Falls, near Hagerman, 1350.

## SOURCES OF THE INFLOW

Analysis of the different sources of the total inflow in the study reach aids in understanding the characteristics of the inflow, in assessing the impact of man's activities, and in predicting future performance of the hydrologic system.

### Inflow from the South Side

Most of the flow entering the study reach from the south side is return flow from water that has previously been utilized for irrigation. The natural surface flows of the southern tributaries are practically all diverted for irrigation during the summer season and the flows are usually small during the nonirrigation season. The South Side Twin Falls Canal (gaging station 0875, see fig. 2), is a major source of the south-side inflow. It diverts about 6.2 acre-feet per acre annually to irrigate 203,000 acres south of the

Snake River. Because consumptive use probably does not exceed about 2.0 acre-feet per acre, it is assumed that most of the excess, about 4.2 acre-feet per acre, or 850,000 acre-feet per year, returns to Snake River in the study reach as subsurface or surface flow from this source.

Inflow in the Milner to Kimberly subreach is from seeps and springs considered to be all south-side flow for purposes of this report even though a few springs, including Devils Washbowl Spring, 0895, are on the north bank. Errors resulting from this approximation are believed to be insignificant compared with other inaccuracies in the estimates of various segments of the inflow.

About two-thirds of the total return flow into the study reach from the south side enters the Snake River in the lower channels of Rock Creek, Cedar Draw, Deep Creek, and Salmon Falls Creek, and above the Kimberly gage, 0900. Records of the return flow in Rock Creek near Twin Falls, 0930, are available from 1921 to 1947. Likewise, records for Cedar Draw, 0935, Deep Creek, 0950, and Salmon Falls Creek, 1080, are available for about 3 years. Totals of the flow into the Snake River from these five main contributors of south-side inflow are shown graphically for water years 1956-58 in figure 10.

Inflow to the study reach from all measurable south-side surface flows, including the channels mentioned, was determined by rounds of measurements to be 1,650 cfs in September 1958, 1,160 cfs in March 1959, and 1,280 cfs in August 1959. Unmeasured inflow from the south side through seeps or inaccessible channels is estimated to be 150 cfs. Utilizing these data, relations between various segments of the inflow previously established, and all other available pertinent data, good estimates of inflow from the south side can be made. The estimated total inflow from the south side for the period 1910-66 averaged about 1,400 cfs. Estimated figures of annual mean inflow from the south side for the period 1922-66 are plotted in figure 10.

## Inflow from the North Side

### Spring inflow

By far the largest inflow to Snake River in the study reach is from the scores of springs that issue from the north side. The known data on the flows of the springs were summarized through 1947 (Nace and others, 1958) and for 1948-67 (Thomas, 1968). Locations of the springs are shown on the maps (figs. 3-6), and flows of representative springs are presented in figure 9. The discharge of some of the springs has changed radically. For instance, measurements of Devils Washbowl Spring at site M0896 increased from 1.15 cfs in 1902 to 12.7 cfs in 1917; averaged 24.0 cfs during the highest 5 years, 1951-55; and decreased to an average of 15.6 cfs during the 4 years 1963-66. Apparently the flow in the springs farthest upstream increased more markedly as a result of surface diversions onto the plain than those near the downstream end of the study reach. Pumping from the Snake Plain aquifer appears to be causing these same springs to recede more than the springs farther downstream.

The total spring flow is considerably greater than the sum of the discharges of all of the individual springs that have been measured at various times. Points of entry of large segments of the unmeasured flow are known. Box Canyon Spring was flowing 480 cfs more at the mouth, site M0956, than at the gaging station, site 0955, on April 6, 1956. Blue Springs, M0957, which probably flows more than 60 cfs, cannot now be measured by regular methods except when the forebay above Upper Salmon Falls Dam is very low. Riley Creek, at the mouth, M1343, is estimated to flow about 120 cfs more than at the regular measuring site, M1338. Concurrent records for the main stem Snake River gaging stations near Hagerman, 1345, and below Lower Salmon Falls, near Hagerman, 1350, show nearly 400 cfs more inflow than in the measured springs in that reach.

All of the unmeasured spring flow can be estimated closely at the times of the three sets of measurements of the south-side inflow. The most important elements of the total spring inflow are known then within close limits. Computations show that the unmeasured spring flow was 1,600 cfs in September 1958, 1,600 cfs in March 1959, and 1,400 cfs in August 1959. Annual means of the total spring discharges have been computed and are shown on the bar graph (fig. 11). These figures are believed to be within a few percent of the actual yearly mean discharge from the western end of the Snake Plain aquifer. As shown by figure 11, total spring flow has ranged from about 4,100 cfs in 1904 and 1907 to about 6,900 cfs in 1953 and was about 6,200 cfs in 1966.

Major diversions from the Malad Springs into the King Hill Canal began in 1930. About 25 percent of the flow in the King Hill Canal returns to the river as return flow from irrigation or from canal leakage and is measured at the King Hill gage. However, about 75 percent of the flow in the King Hill Canal bypasses the King Hill gage or is used consumptively upstream. To reflect more accurately the total contribution from these springs, 75 percent of the flow in the King Hill Canal is included in the total spring discharge shown in figure 11. As previously noted, the flow in King Hill Canal was not added to the inflow, Milner to King Hill, since the inflow in the study reach was intended to represent the unobligated water supply entering the reach. However, the total spring inflow represents the discharge from the

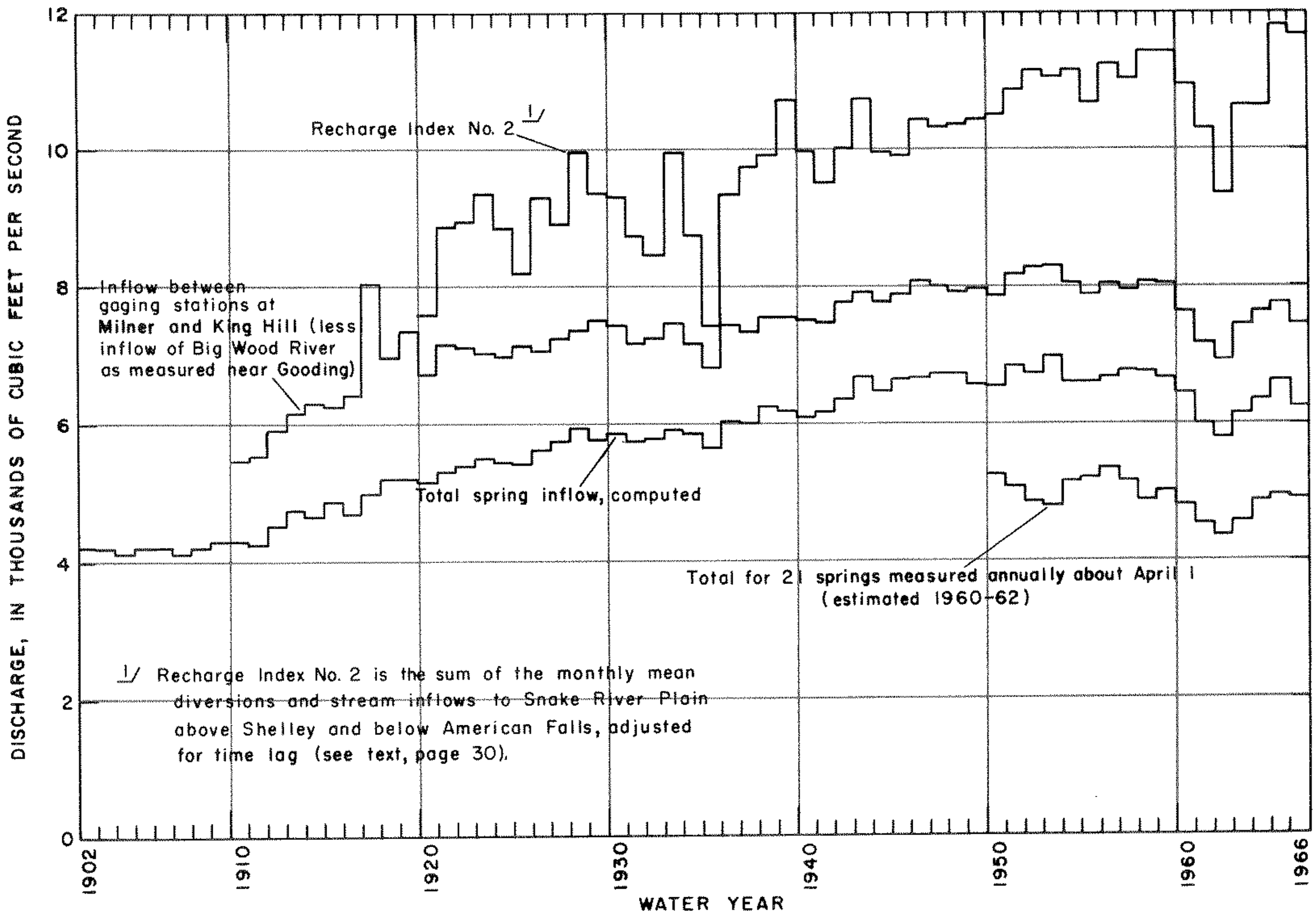


FIGURE 11. Inflow to the study reach, total spring flow, and Recharge Index No. 2.

Snake Plain aquifer, of which the King Hill Canal water is a part.

Total discharge of the north-side springs as estimated for the period 1910-66 averaged 5,900 cfs.

## Surface Inflow

Most of the surface return flow from irrigation on the north side spills over the rimrock into the deep box canyons, coves, or channels associated with the major springs (J. R. Spofford, U. S. Geological Survey, Boise, Idaho, 1968, oral commun.). At the times of the annual spring measurements, this surface return flow was also measured. The average of 13 sets of measurements of return flow made during the periods 1950-59 and 1963-65 was 63 cfs. Practically no flow was reported in 1956 and 1964, but nearly 200 cfs was measured in 1965. Data from the North Side Canal Co., Ltd., showed that surface return flow from the north side averaged 100 cfs during 1958. An average of 100 cfs has been used in this report and is believed to be reasonable.

The hydrograph of the total inflow, Milner to King Hill (fig. 8), shows irregularities during years prior to 1925 that are not characteristic of later years. For example, high apparent inflows for some months in 1910, 1916, and 1919 were evidently caused by unusual local runoff or by large winter diversions in the canals above Milner. These unusual flows have been lowered to figures more characteristic of flows occurring in the spring of the year in estimating the discharge from springs for those years.

Big Wood River and Clover Creek are the only surface streams that flow directly into the Snake River from the north bank in the study reach. The Big Wood River has been gaged for long periods at the station near Gooding, 1525. Since this flow is sometimes rather large and is unrelated to the other inflow in the study reach, it has been subtracted from the figures of total inflow as noted in the introduction to this report. Flow in Clover Creek, 1540, averages only about 30 cfs and has been treated as unmeasured inflow in computations for this study.

## FACTORS AFFECTING THE INFLOW

The spreading of water on the Snake River Plain for irrigation has resulted in a net increase in recharge to the aquifer, and thus increased return flow to Snake River. Diversions per acre of land irrigated on the Snake River Plain are comparatively high, and much of the water diverted returns to the Snake River in the study reach. The bar graph (fig. 11) shows inflow to the study reach and estimated total flows of the springs. Irrigation on the plain began near Idaho Falls in 1870. By 1900, more than 0.4 million acres were reclaimed, and by 1960, about 2.1 million acres were being irrigated by surface water diversions and ground-water withdrawals.

Pumping from the Snake Plain aquifer onto the Snake River Plain began in 1946 and has increased progressively. The consumptive part of this pumpage is another discharge from the aquifer.

In addition to the increasing the inflow to the Snake River in the study reach, the diversions onto the plain and other recharge sources cause a cyclical variation in the spring flows and in the total inflow. Recharge Index No. 1, described earlier in the report, has been used in figure 9 to portray graphically some of the relations between recharge factors and inflow to the river.

Figure 9 indicates that the annual cycles of inflow to the study reach are related to the cycles of the recharge supply. The recession of the annual cycle each year is arrested soon after the irrigation season begins. The inflow hydrograph begins to rise noticeably about a month after heavy irrigation diversions begin, and the decline resumes about a month after the heavy irrigation season ends. It should be noted that the high runoff from natural streams, which is a part of the recharge index, is approximately coincident with the start of the irrigation season; hence, the effects are additive except as they are affected by time lags.

Following years of low diversions such as 1934 and 1961, inflow to Snake River, and the amplitude of the cyclical changes are lower than during average years. Likewise, increased recharge results in corresponding increases in the inflow and in the amplitude of the cyclical changes.

## CORRELATIONS OF THE INFLOW TO THE REACH AND THE SPRING FLOW WITH A RECHARGE INDEX

A second recharge index was derived, designated Recharge Index No. 2, which is the sum of diversions from the main stem of Snake River below Neeley (fig. 1) and above Shelley, diversions from Henrys Fork and tributaries, streams on the north side from Mud Lake to Big Wood River, and streams on the south side below Neeley.

Before combining the elements of recharge below Neeley and those above Shelley for the correlation, the flows were adjusted somewhat arbitrarily because there is a lag in time between a recognizable recharge event and a corresponding inflow to the study reach. Also, the lag time would vary with the distance of the recharge event from the study reach. Consequently, the figures used for elements above Shelley are the averages for the current year and the previous year. The figures used for elements below Neeley are the averages for the 12 months from July of the previous year until June of the current year.

Figure 11 illustrates how this recharge index follows the trends of the inflow to the study reach.

## Correlation with the Inflow to the Reach

Empirical relations between this recharge index and the inflow to Snake River in the study reach are shown on figure 12. All points on figure 12 are within about 8 percent of the average regression line for the period 1920 to 1966. The standard error is less than 5 percent. Plotting positions in the figure appear to group by years. For instance, the points for the period 1920-41 are all within 3 percent of a regression line drawn through those points. Similarly, points for three other periods are all within 3 percent of their respective regression lines except 1966, which indicates a continuation of the trend in recent years for the plotting positions to move farther to the right.

Changes in regimen in the Snake Plain aquifer appear to explain these groupings. During the period 1920-41, the aquifer was filling as a result of diversions onto the Plain. During the same period, consumptive use on newly irrigated lands reduced recharge from the tributaries bordering the Snake River Plain. During the period 1942-53, the aquifer was approximately in equilibrium, diversions were large, and effects of pumping ground water from the aquifer were minor. Pumping from the aquifer affected the gradients, elevations, and the discharge from the aquifer during the periods 1954-59 and 1960-66. During the period 1960-66, pumping apparently reduced the inflow in the study reach 600-700 cfs from the rate reached during 1942-53. The plotting positions from 1965 and 1966 indicate that a new curve to the right of that shown for 1960-66 may now be applicable (fig. 12).

Figure 13 shows the relation between departure of inflow from the 1942-53 curve of figure 12 and net ground-water pumpage in the Minidoka-Shoshone area for the years 1954-66. Net ground-water pumpage, that part of

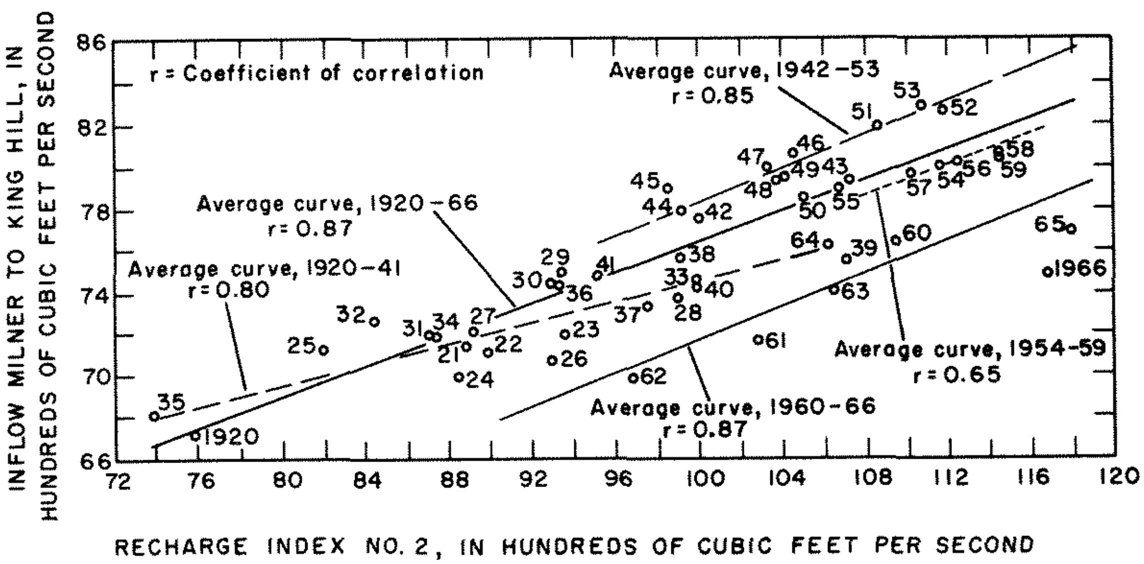


FIGURE 12. Relation of Recharge Index No. 2

to the inflow tc the study reach.

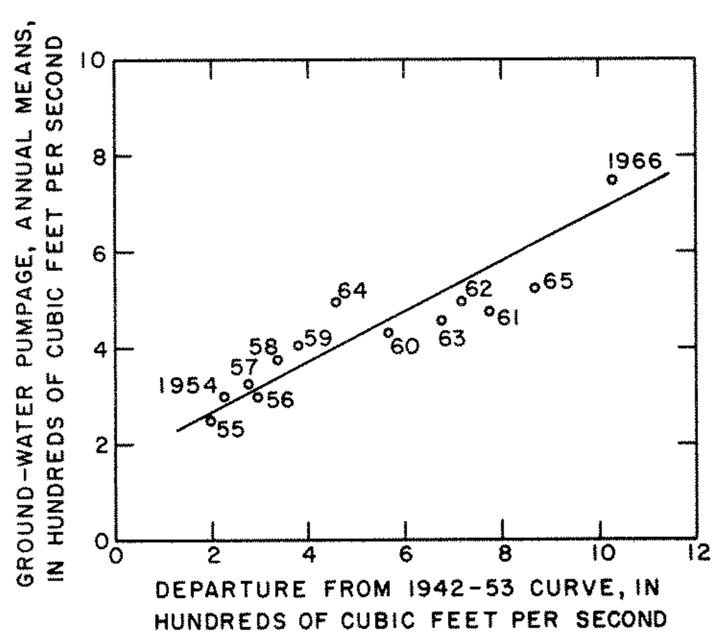


FIGURE 13. Relation between departures from the 1942-53 curve, figure 12, and the net pumpage in the Minidoka-Shoshone area.

the pumped water that is used consumptively, was estimated for each year from data on crop requirements and miscellaneous losses for nearby projects adjusted for rainfall (unpub. data). The correlation in figure 13 indicates that most of the departure for the 13 years from the 1942-53 curve of figure 12 results from the pumpage or a related effect. A statistical test of the significance shows that 95 percent of the time points on figure 12 would plot within about 3 percent of the 1942-53 curve after adjusting for the net pumpage.

### Correlation with the Spring Flow

The spring inflow as well as the total inflow into the reach correlates significantly with Recharge Index No. 2. The plotting of the points on figure 14 suggests that for the period 1920 to 1940 the aquifer was filling and the springs reacted to changes in recharge to the aquifer to a lesser degree than during the period 1941 to 1953. Pumping from the aquifer began about 1946 and became significant by about 1954.

Net ground-water pumpage from the aquifer in the Minidoka-Shoshone area and departure from the curve of relation for 1941 to 1953 of figure 14 are compared on figure 15. Because the degree of correlation is high, as shown by the plotted points, the effect of pumpage on the spring discharge can be predicted with considerable assurance.

From figure 12, it can be seen that if a recharge index can be forecast, then inflow can also be forecast by use of the appropriate curve. Estimates of streamflow and diversions onto the plain based on snow surveys and reservoir storage for April 1 can be made with considerable confidence. From these, forecasts of the inflow to the reach for the next 12 months can be made (Thomas, 1967). The ability to forecast the magnitude and major

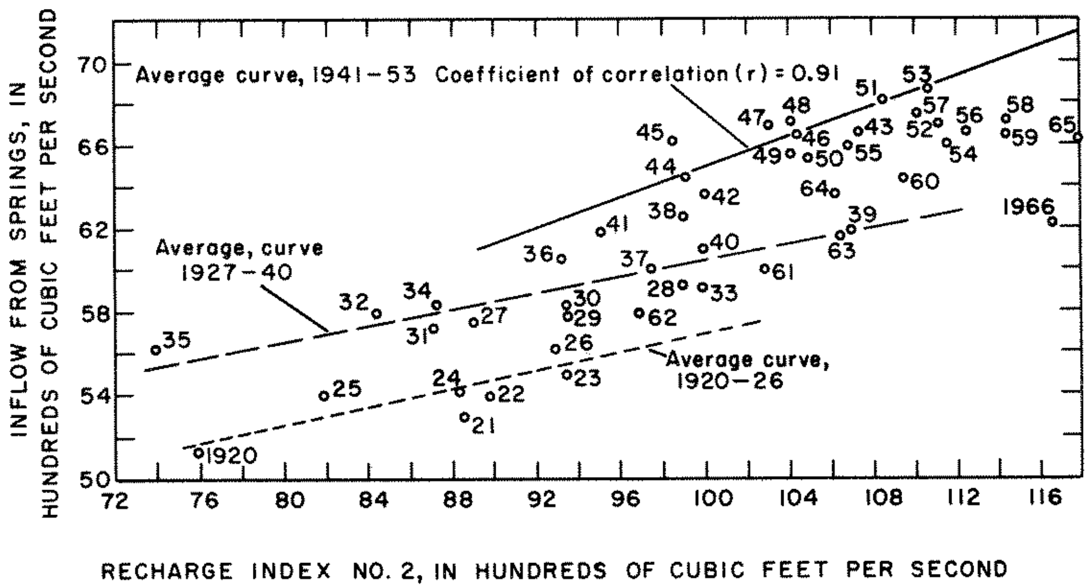


FIGURE 14. Relation between Recharge Index No. 2 and the inflow from springs in the study reach.

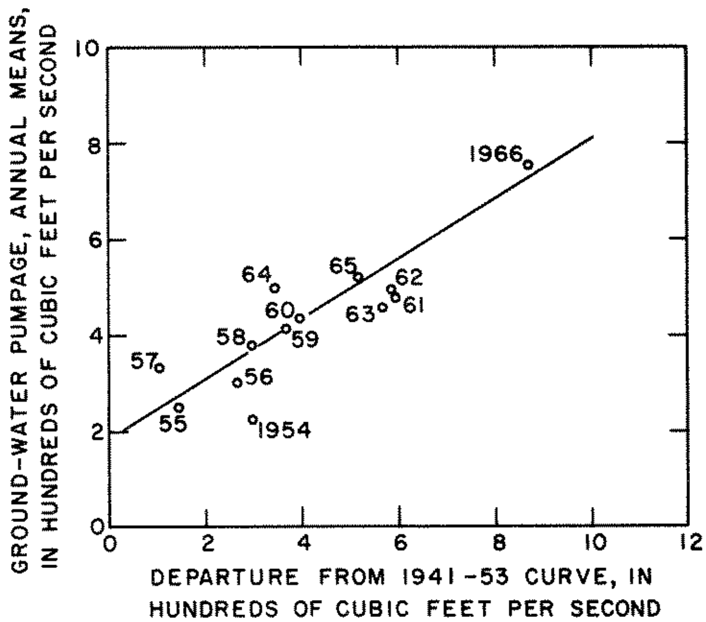


FIGURE 15. Relation between departures from the 1941-53 curve, figure 14, and the net pumpage in the Minidoka-Shoshone area.

variations in this inflow is of considerable value for water management purposes. By using a computerized approach, a relation which would give better estimates of the inflow to the reach using different assumptions to take care of the time lag could no doubt be found.

In addition to their value for predicting the flows into the study reach, figures 12-15 are useful in evaluating effects on the flow from changes in irrigation, artificial recharge, pumping, and other water-use practices. For example, the relations indicate that spring flow decreases the same year that pumping from the aquifer is increased. Likewise, after allowing for a relatively short time lag, both the spring inflow and the total inflow to the reach rise and fall with the recharge index.

## QUALITY OF THE WATER

Chemical analyses of water from various springs on file in the Boise, Idaho, office of the U. S. Geological Survey indicate that the dissolved solids in water entering the Snake River from springs between Milner Dam and King Hill averages about 260 mg/l (milligrams per liter and parts per million are numerically equivalent in the ranges of concentration found in these waters). The analyses show that the concentrations in the water of the springs decrease approximately in downstream order; that is, the highest concentrations are in springs farthest upstream and the lowest concentrations are in the springs farthest downstream. The dissolved solids in the discharge from the larger springs range from 382 mg/l in Blue Lakes Springs (0910) to 217 mg/l in Riley Creek (1343). Chemical analyses of water from four of the larger drainage channels from the south side, most of which is return flow from irrigation, show that the concentrations of dissolved solids were considerably higher than in the springs and averaged about 560 mg/l.

These higher concentrations may be due to prior use of this water for irrigation, to differing geologic environments, or to causes unknown. No consistent pattern of change in dissolved-solids content with respect to location was noted for the south-side inflows.

On the basis of weighted averages, the inflow to the reach was determined to contain 328 mg/l of dissolved solids. This figure is substantiated by the observation that the dissolved-solids content of the flow in Snake River at King Hill, 1545, for the 1961 water year averaged 326 mg/l. During that year, about 97 percent of the flow at King Hill was derived from inflow to the study reach.

In all samples, the sodium percentage is relatively low indicating a low sodium hazard with regard to use of this water for irrigation. The water from all sources generally is excellent for irrigation. Treatment for hardness may be necessary for some industrial uses. The water, even from the springs, requires treatment for biological hazards if used for municipal supplies. Although the flow from the springs is crystal clear, flow off the irrigated lands, industrial wastes, high flows past Milner, and aquatic growths contribute to turbidity and to varying amounts of pollution in the river.

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